

Supervised Neural Networks for Helioseismic Ring Diagram Inversions

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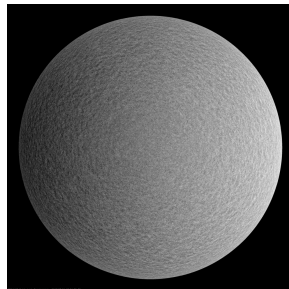
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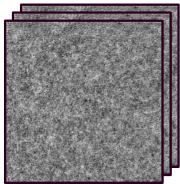
The Solar Subsurface

- Direct imaging is impossible
- Inferences made from observed surface wave field
- Flows cause frequency shifts



HMI Dopplergram^[1]

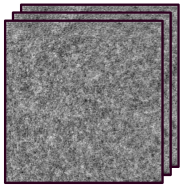
¹sdo.gsfc.nasa.gov/



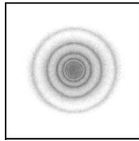
Tracked
 15° Patch

¹Basu et al. 1999

²Greer 2015



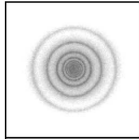
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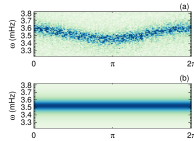
$$P(k_x, k_y, \omega)^{[1]}$$

¹Basu et al. 1999

²Greer 2015



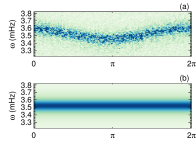
$$P(k_x, k_y, \omega)^{[1]}$$



Slice at fixed
 $|k|^{[2]}$

¹Basu et al. 1999

²Greer 2015



$$[U_x^{n,\ell}, U_y^{n,\ell}]$$

Slice at fixed
 $|k|^{[2]}$

¹Basu et al. 1999

²Greer 2015

$$\begin{aligned}
 u_x(z_t) &= \sum_{n,\ell} c_{n,\ell}(z_t) u_x^{n,\ell} \\
 &= \boxed{\sum_{n,\ell} \int c_{n,\ell}(z_t) K^{n,\ell}(z) u_x(z) dz} \quad \text{Linear?} \quad (1)
 \end{aligned}$$

Computationally expensive [31 CPU hrs/CR]

¹Basu et al. 1999

²Greer 2015

Why use machine learning?

- Solves non-linear problems
- Lots of data (>700,000 observations)
- Greatly reduces computational burden
- Replace current procedure

What's involved?

- Supervised Learning
- Preprocessing data
- Model optimization

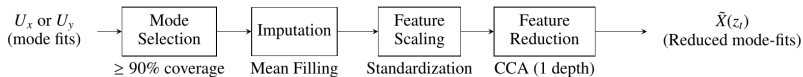
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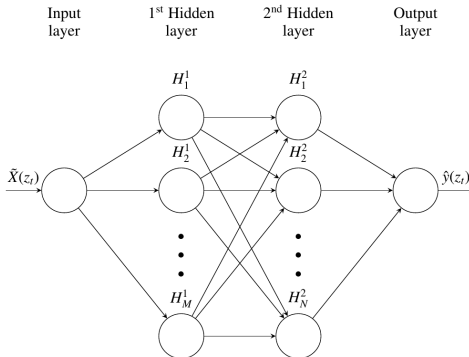
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Preprocessing

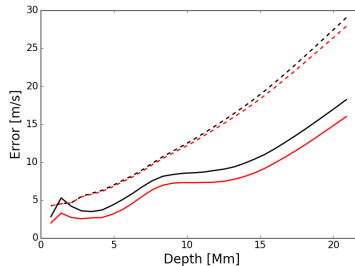


Artificial Neural Network



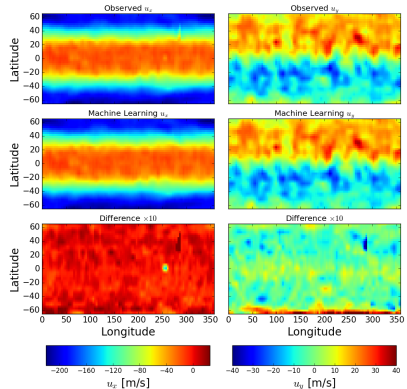
ML	Train & Prediction Time [s]		RMSE (m/s)	
	u_x	u_y	u_x	u_y
Lin	< 1	< 1	8.8	7.3
Bay	< 1	< 1	8.8	7.3
DT	19	20	8.8	7.4
RF	39	42	10.5	9.0
KNN	50	35	9.0	7.7
ANN	360	194	8.6	7.3
SVR	61441	47555	8.5	7.3

For $z_t = 10.44$ Mm



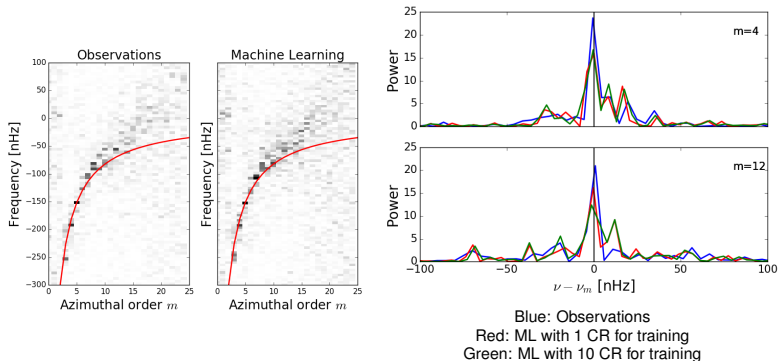
Black: u_x , Red: u_y
Dashed: Observed, Solid: ML

- Flows are recovered
- Some ‘junk’ not present in ML
- Have we lost something?



Have we lost some helioseismic signatures?

Can we detect Rossby waves (Löptien et al. 2018) in ML?



Did we succeed?

- ML can be used to accurately predict future observations
- Training for all depths: < 5 CPU hrs [using entire SDO obs]
- Predictions for next CR: < 1 CPU sec [old: 31 CPU hrs]

Future: Dopplergram $\rightarrow$ Flows